1,165,902

PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in Electrohydraulic Forming

We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, a British Corporation, of Kingsgate House, 66-74 Victoria Steret, London, S.W.1. do hereby declare the invention, for which we pray that a patent may be granted to us and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to electrohydraulic forming, and is particularly concerned with a method of an apparatus for electrohydraulically forming metal and plastics materials. However, the invention is not limited to the use of such materials and is generally applicable to the forming of any material whose characteristics permit it to be pressed into a die to take up a deformed shape and which then retains that shape corresponding to the configuration of the die when the deforming pressure is released.

It is well-known that sheet material can be formed into a desired shape by purely hydraulic methods by placing one surface of the sheet material against a die and subjecting the other surface, when in contact with a liquid, for example, oil or water, to a pressure developed in the liquid. The sheet material is thereby forced into intimate contact with the died and takes up a shape exactly corresponding to the contours of the die.

It is know that such pressures can be developed by raising the pressure generally in the liquid in contact with the sheet material to a high value, or by causing a high pressure shock wave to be generated in the liquid by effecting an electrical discharge between a pair of electrodes immersed in the liquid.

The former, purely hydraulic, method has the disadvantage that it requires the use of expensive and robust dies and pumping equipment in view of the extremely high hydraulic pressures which are required for satisfactory operation. Moreover, this method entails limitations in the shapes into which the material can be formed, since fine detailed and complex shapes in the formed article are difficult to attain by this method alone.

The latter, electrohydraulic, method where a high pressure shock wave is caused by an electrical discharge enables more intricate and detailed shapes to be formed than when using purely hydraulic methods. Such electrohydraulic forming generally requires, however, the use of a large bank of condensers for storing the electrical energy to be discharged between the electrodes and this necessarily involves a high capital cost. Moreover, in view of the high voltage discharge required, the electrodes, which are expensive to replace, are found to have a short life, thus increasing the operational costs.

The present invention results from the realisation that the two above-mentioned methods are not mutually exclusive, and that by adopting a method which embodies a combination of the two known methods equivalent or better results can be obtained with a substantial saving in cost.

In accordance with the present invention, there is provided a method of electrohydraulically forming an article which comprises the steps of placing an unformed article in close proximity to a die, subjecting the unformed article to a hydrostatic pressure in a sense to urge the article into the die by compression of a liquid medium, and while maintaining said hydrostatic pressure generating a shock wave in the liquid medium by causing an electrical discharge therein such that the sum of the hydrostatic pressure and the pressure of the shock wave is then sufficient to form the article in the die.

[*Price* 4*s*. 6*d*.]

Also in accordance with the present invention, there is provided apparatus for electrohydraulically forming an article comprising a die shaped to the configuration of the desired article and arranged to receive an unformed article in close proximity thereto, a liquid chamber arranged to be partially bounded by the unformed article, pressurisation means arranged to generate and maintain a hydrostatic pressure within said chamber, and electrode means arranged to provide an electrical discharge within the liquid medium in said chamber to create a pressure wave which in combination with the hydrostatic pressure is sufficient to form the article in the die.

The amount of electrical energy which is required to cause a sufficiently strong transient high pressure shock wave to form the article will vary according to the magnitude of the hydrostatic pressure which is applied, but the total amount of energy required to form the article will remain constant.

Preferably, the hydrostatic pressure which is exerted on the unformed article is such as to cause the material of the article to be subjected to a stress slightly below its yield point. It has been found that this results in a highly economical manufacture of the article.

Thus, where the electrical discharge is obtained from the release of energy stored in a bank of condensers, a proportionately smaller bank of condensers can be used as compared with known systems using no supplementary hydrostatic pressure.

The invention is of particular application to the electrohydraulic forming of sheet material which is provided as a flat plate or as a tube in the pre-formed state.

In order that the invention may be fully understood, two embodiments thereof will now be described in detail by way of example and with reference to the accompanying drawings, in which: —

FIG. 1, is a vertical sectional view through an electrohydraulic tube forming machine in accordance with the invention;

FIG. 2. is a sectional view of the electrode mounting structure which is positioned at each side of the machine, the parts at each side of the machine being identical;

FIG. 3. is a vertical sectional view through an electrohydraulic plate forming machine in accordance with the invention; and,

FIG. 4. is a sectional view, on an enlarged scale, through an electrode assembly suitable for use in the machine shown in Fig. 3.

Referring first to FIG. 1, the electrohydraulic tube forming machine shown therein uses sheet-form material which is made into a tube which is inserted into a female die. In the forming operation, as will be explained more fully later, the tube is filled with liquid under pressure and is expanded outwardly into the female die. The invention can equally well be applied however to an arrangement wherein the tube is fitted over a male die and is compressed inwardly into the die.

The machine comprises a base 10 upon which the other components are mounted and which rests upon a plane floor or other surface. On the base 10 there is mounted a right-hand support 12 and a left-hand support 14. These supports 12, 14 are shaped as dished plates resting on edge and each have a horizontally extending aperture formed therethrough. On top of the support 12, 14 there is mounted an upper tie 16 in the form of a substantially flat plate. Extending vertically down through the upper tie 16 and secured in the base 10 are a plurality of the tie rods 18, two of which are shown in the drawing.

The tie rods 18 hold an upper plate 20 which carries above it a pressure cylinder 22 having a piston rod 24 associated therewith extending downwardly through a hole in the upper tie 16. The lower end of the piston rod 24 terminates in an adapter 26 bolted to the piston rod. A guide plate 28 which is movable vertically on the tie rods 18 fits the lower end of the adapter 26 and is secured thereto so that as the cylinder 22 is pressurised the guide plate 28 is caused to move up or down accordingly.

The guide plate 28 carries an upper tool holder 30 secured to its underside. Correspondingly, a lower tool holder 32 is mounted on the base 10 facing the upper tool holder 30. The upper and lower tool holders 30, 32 encompass a tooling sub-assembly or die 34. In this embodiment the die 34 is cylindrical and the tool holders are preferably each semi-cylindrical to provide adequate support for the die. Within the die 34 is placed the tube 36 to be formed. This tube 36 is preferably produced from a strip of material which is cut to the required length and rolled into its cylindrical configuration. The length of the tube 36 must always be slightly less than the horizontal length dimension of the die 34 to ensure satisfactory sealing, a typical figure for the difference being between 0.005 and 0.03 inches. As can be seen from the drawing, the tube 36 is closed at its ends by a left-hand plug 38a and a right-hand plug 38b the plugs being glued into the ends of the tube and O-ring seals 40 ensuring perfect sealing of the joints. The interior of the tube 36 defines a pressure chamber 42 which is filled with the liquid medium, e.g. water or oil, during the forming process. Access to the pressure chamber 42 for the liquid medium is by way of a passageway 44 formed through the right-hand plug 38b, this passageway being suitably connected to a source (not shown) of the medium.

The die 34 has its surface adjacent to the tube 36 shaped concavely to receive the

material of the tube during the forming process. This annular recess 46 is vented to atmosphere via a passageway 48 extending through the die and the lower tool holder.

Mounted at the left-hand side of the machine between the die assembly and the left-hand support 14 is a pressure cylinder 50 having an associated piston rod 52. The end of the piston rod 52 has an adapter 54 secured thereto which fits over the left-hand plug 38a and is pressed against the plug in pressure-sealing relationship therewith when the cylinder 50 is pressurised.

The right-hand plug 38b similarly has an adapter 56 encompassing it in pressure-sealing relationship. This adapter 56 is secured to a cylindrical screw 58 which engages with a nut 60 mounted in a bush 62 seated in the aperture in the right-hand support 12. The adapter 56 is prevented from rotational movement by a key 64 mounted in a key holder 66 secured to the base 10, but the adapter and screw are capable of axial adjustment with subsequent locking in position by means of the nut 60. Such axial adjustment is necessary to enable dies of different sizes to be accommodated and positioned within the machine.

It will be seen from the drawings that within the pressure chamber 42 there are two electrodes, a left-hand electrode 68a and a right-hand electrode 68b. These electrodes and their associated mounting structure at each side of the machine are identical and only one will therefore be described.

The right-hand electrode 68b extends from the pressure chamber 42 through the plug 38b, the adapter 56, and the screw 58 to an insulated connector 70 (Fig. 2). An adjusting bracket 72 is secured to the outside of the right-hand support 12 and is tightened against a thrust plate 74. At its outer end the bracket 72 holds a bush 76 in which is seated an adjusting unt 78. Extending through the nut 78 is a hollow adjusting screw 80 which carries a pressure cylinder 82 at its outer end. The piston rod associated with the cylinder 82 extends through the screw 80 and is connected to a tie bar 84 which is secured at its other end to the insulated connector 70. A key 86 mounted in the bush 76 engages in a keyway in the adjusting screw 80 and a lock nut 88 is provided on the screw 80 to enable the assembly to be clamped in its adjusted position. By this means, the electrode can be positioned accurately within the chamber 42 and is subjected to a longitudinal pressure force from the cylinder 82 which sufficiently balances the pressure in the chamber 42 to prevent an axial displacement of the electrode.

The electrical connections to the electrode are not shown in the drawings but are made to the insulated connector 70 and will be apparent to those skilled in the art. The bracket 72 is apertured at 90 to accommodate the electrical leads.

The foregoing description should make the method of operating the machine quite apparent but a brief summary of the forming process will now be given.

Initially, the tube 36 is prepared from a strip of the desired material by cutting it to the required length. This length is then scarfed and glued to the plugs 38a and 38b with the O-ring seals 40 in place. With the pressure cylinders 22, 50 and 82 unpressurised and the respective piston rods retracted, the tube and plug sub-assembly is placed in position within the die 34 which is then closed around the tube. Preparatory to this, the screw 58 and right-hand adapter 56 are axially set to the correct position for the particular die size.

By initial pressurisation of cylinders 22 and 50 with a hydraulic actuating medium, usually oil, through suitable piping (not shown) the guide plate 28 and upper tool holder 30 on the one hand and the left-hand adapter 54 on the other hand are moved towards the die. Pressurisation of the two electrode cylinders 82 is then effected so that the electrodes 68a and 68b are advanced into the pressure chamber 42 to the correct setting.

When a clamping pressure is exerted on the die the pressure chamber 42 is filled with the hydraulic medium via passageway 44 and simultaneously the pressures exerted by the various pressure cylinders are increased correspondingly. When the desired hydrostatic pressure in the chamber 42 has been reached, an electrical discharge is generated between the electrodes 68a and 68b, for example by connection to a bank of condensers, and a high pressure shock wave is thus set up in the chamber. This, in combination with the hydrostatic pressure, is sufficient to cause the tube to be deformed into the recess 46 in the die and to take up its formed shape.

After the forming of the tube, the chamber 42 can be exhausted of the hydraulic medium and the various cylinders de-pressurised. This is followed by retraction of the respective piston rods so that the formed article can be removed from the machine. In a typical machine the pressure in the chamber 42 may be 5000 p.s.i. maximum, and the maximum pressures available from the cylinders would then be 5000 p.s.i. from cylinders 22 and 50 and 1500 p.s.i. from cylinders 82. A particularly economical method of operating the machine has been found to consist in establishing a hydrostatic pressure in the chamber 42 such that the tube material is stressed to just below its yield point and then initiating the electrical discharge to effect the desired forming of the tube.

Referring now to Figs. 3 and 4, this shows

an electrohydraulic plate forming machine arranged to operate on the same principle as the tube forming machine hereinbefore described. The machine comprises a base 100 and a pressure cylinder 102 mounted in a fixed position above the base on a number of pillars 104, only two of which are shown. Within the cylinder 102 a ram 106 is reciprocally movable and has a piston rod 108 secured to its upper surface and extending through a bush 110 in the top of the cylinder. The piston rod 108 is sealed in the bush 110 by a pair of seals 112 and seal retainers 114, and an O-ring seal 116 seals the bush in the cylinder. Two annular seals 118 are also provided around the peripheral surface of the ram 106 and are held in place by seal retainers 120. The lower end of the ram 106 depends below the bottom of the cylinder and carries an adapter 122 bolted thereto. This adapter 122 is shaped to fit a die element within which the plate itself is mounted. The sub-assembly of the die element and plate to be formed is not shown in the drawing but its position within the machine is clearly apparent. The lower part of the die is formed by a block 124 mounted on the top of the base 100. This block 124 is recessed at its upper surface to define a liquid chamber 126. Centrally positioned within the block 124 and extending upwardly therethrough into the chamber 126 is an electrode assembly 128 which is shown clearly in Fig. 4.

As can be seen in Fig. 3, a safety ring 130 is secured to the bottom surface of the cylinders 102 in overlapping relationship therewith so as to prevent excessive downward movement of the ram 106. A key (not shown) extends horizontally through the safety ring 130 to engage in a keyway in the ram 106 to prevent rotational movement thereof.

The electrode assembly 128 shown in Fig. 4 comprises a central electrically conductive rod 132, for example of copper, surrounded by an insulating sheath 134, such as nylon. Around the upper shaft of the sheath 134 and in contact with the wall of the bore in the block 124 is an electrically conductive tube 136, for example of brass. The upper end of this tube is shaped in the form of a crown 138 so that the central rod 132 is effectively surrounded by the outer electrode. The lower end of the central rod 132 is connected via a connector 140 to an electrical supply lead 142 and is enclosed within a shield 144 and insulator sleeve 146. Thus, by suitable electrical connections a discharge can be obtained between the rod 132 and the crown 138 within the liquid, e.g. water, in the chamber 126.

In operation, the ram 106 is caused to move downwards by pressurisation of the cylinder 102 via hydraulic piping (not shown), and when the adapter 122 is in clamping engagement with the sub-assembly tooling the pressure of the liquid in chamber 126 is suitably increased until the desired hydrostatic pressure is achieved. The electrode assembly is then connected to a suitable potential source and a discharge occurs between the electrodes, generating a shock wave, and forming the plate which is held across the mouth of the die.

Tests have shown that the formation, in a sheet of 16 gauge stainless steel, of a part-spherical dimple of 10.2. cm. diameter and 1.4. cm. depth required 6K joules of electrical energy to be discharged between electrodes when no hydrostatic pressure was involved. When a hydrostatic pressure of 2,500 p.s.i. which is sufficient to subject the steel sheet to a stress slightly below its yield point, existed in the liquid during the discharge, only 1.5K joules of electrical energy were required to obtain the same effect.

WHAT WE CLAIM IS:—

1. A method of electrohydraulically forming an article which comprises the steps of placing an unformed article in close proximity to a die, subjecting the unformed article to a hydrostatic pressure in a sense to urge the article into the die by compression of a liquid medium, and while maintaining said hydrostatic pressure generating a shock wave in the liquid medium by causing an electrical discharge therein such that the sum of the hydrostatic pressure and the pressure of the shock wave is then sufficient to form the article in the die.

2. A method as claimed in claim 1, wherein the hydrostatic pressure which is exerted on the article is such as to cause the material of the article to be subjected to a stress slightly below its yield point.

3. A method as claimed in claim 1, or 2, wherein the hydrostatic pressure is not greater than 5000 p.s.i.

4. A method as claimed in any preceding claim, wherein the unformed article is a cylindrical tube which is inserted within the die.

5. A method as claimed in any of claims 1 to 3, wherein the unformed article is a flat plate.

6. A method of electrohydraulically forming an article substantially as hereinbefore described with reference to Figs. 1 and 2 or Figs. 3 and 4 of the accompanying drawings.

7. Apparatus for electrohydraulically forming an article comprising a die shaped to the configuration of the desired article and arranged to receive an unformed article in close proximity thereto, a liquid chamber arranged to be partially bounded by the unformed article, pressurisation means arranged to generate and maintain a hydrostatic pressure within said chamber, and electrode means arranged to provide an electrical discharge with-

in the liquid medium in said chamber to create a pressure wave which in combination with the hydrostatic pressure is sufficient to form the article in the die.

8. Apparatus as claimed in claim 7, wherein said pressurisation means comprises at least one hydraulically actuated ram positioned externally of the die and arranged to balance the pressure in said chamber to maintain sealing thereof.

9. Apparatus as claimed in claim 7 or 8, wherein said electrode means comprises a pair of electrodes extending into said liquid chamber in predetermined spaced relationship.

10. Apparatus as claimed in claim 9, wherein said electrodes are capable of positional adjustment within said chamber.

11. Apparatus as claimed in any of claims 7 to 10, wherein the die is essentially cylindrical and the unformed article is to a cylindrical tube.

12. Apparatus as claimed in claim 11, wherein the die is a hollow tube and the unformed article is positioned within the die, the ends of the tubular article being closed by sealing plugs through which said electrode means pass.

13. Apparatus as claimed in any of claims 7 to 9, wherein the die is shaped to receive an unformed article in the form of a flat plate.

14. Apparatus as claimed in claim 13, wherein said electrode means comprises a pair of concentric electrodes separated by an insulating sleeve and extending through one wall of the liquid chamber.

15. Apparatus for electrohydraulically forming an article substantially as hereinbefore described with reference to Figs. 1 and 2 or Figs. 3 and 4 of the accompanying drawings.

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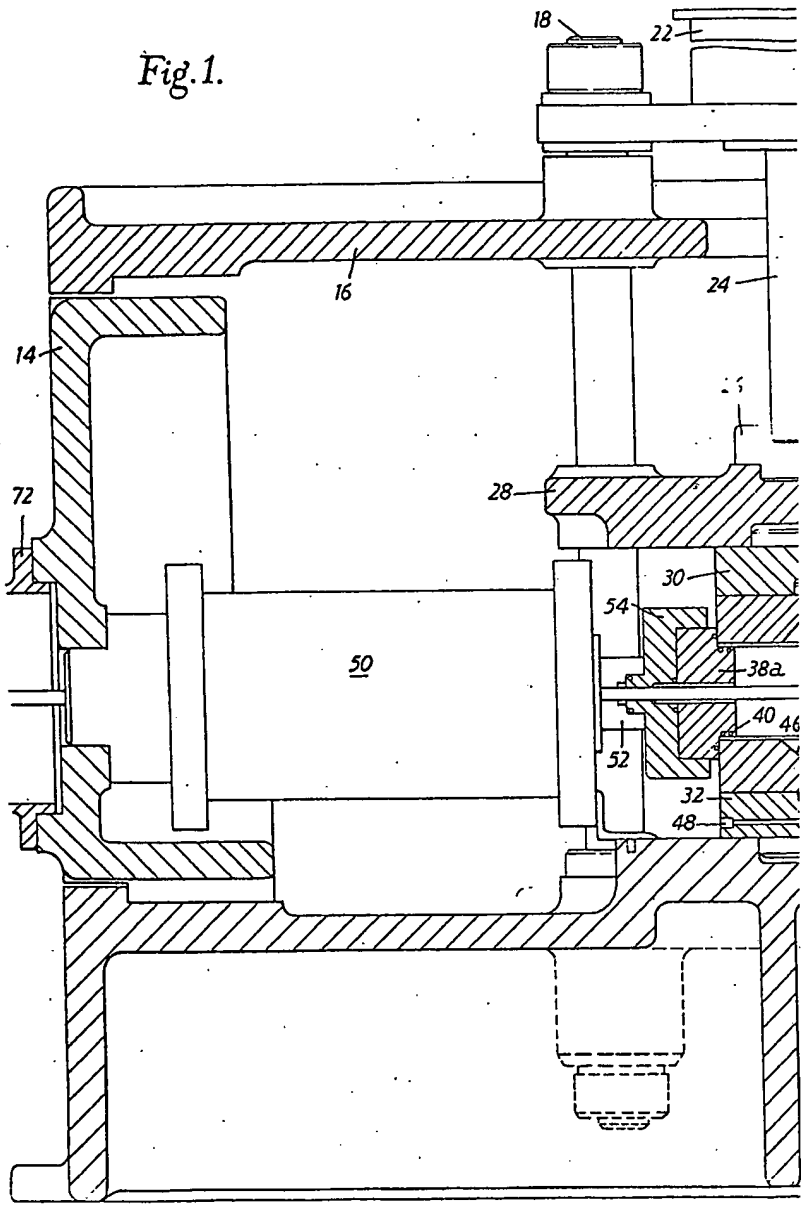
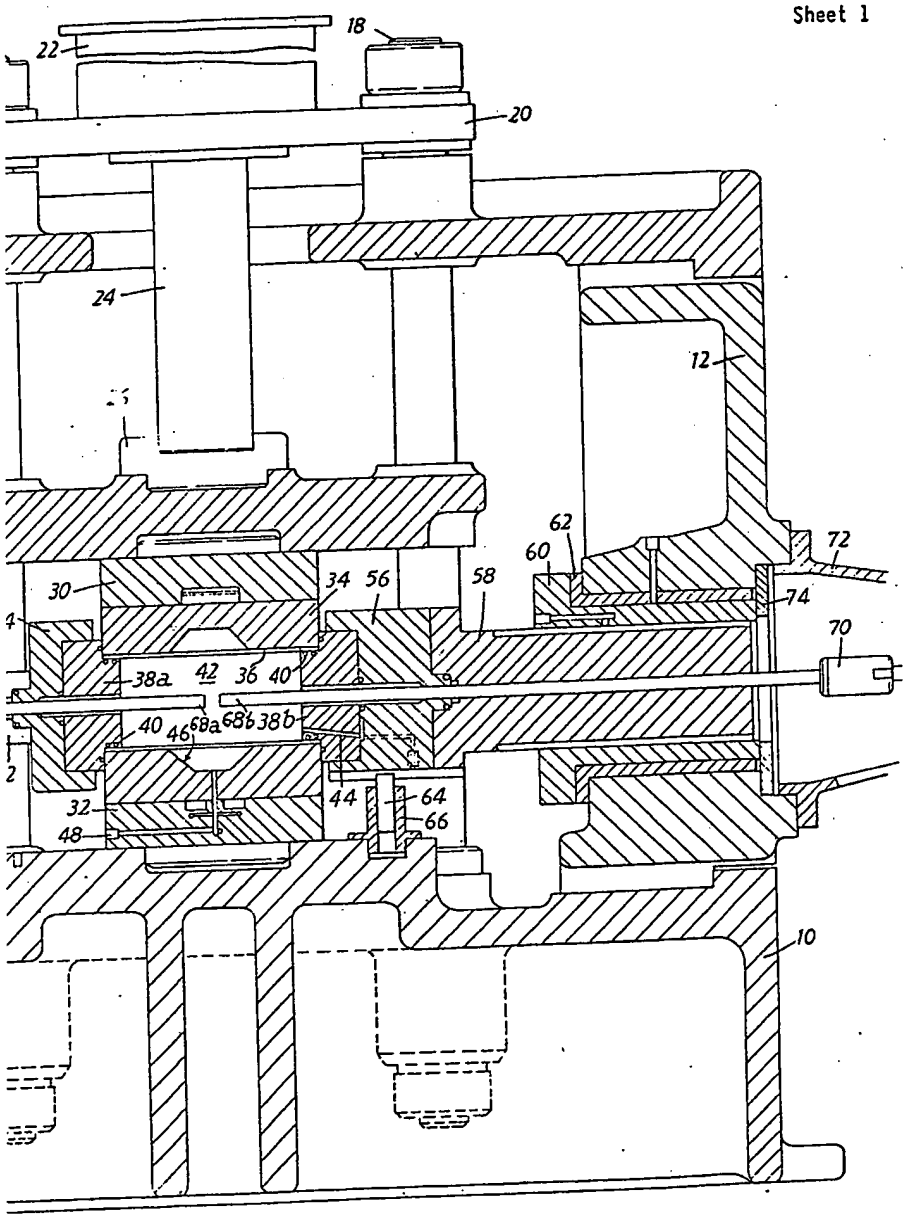
Fig.1.



1165902 COMPLETE SPECIFICATION

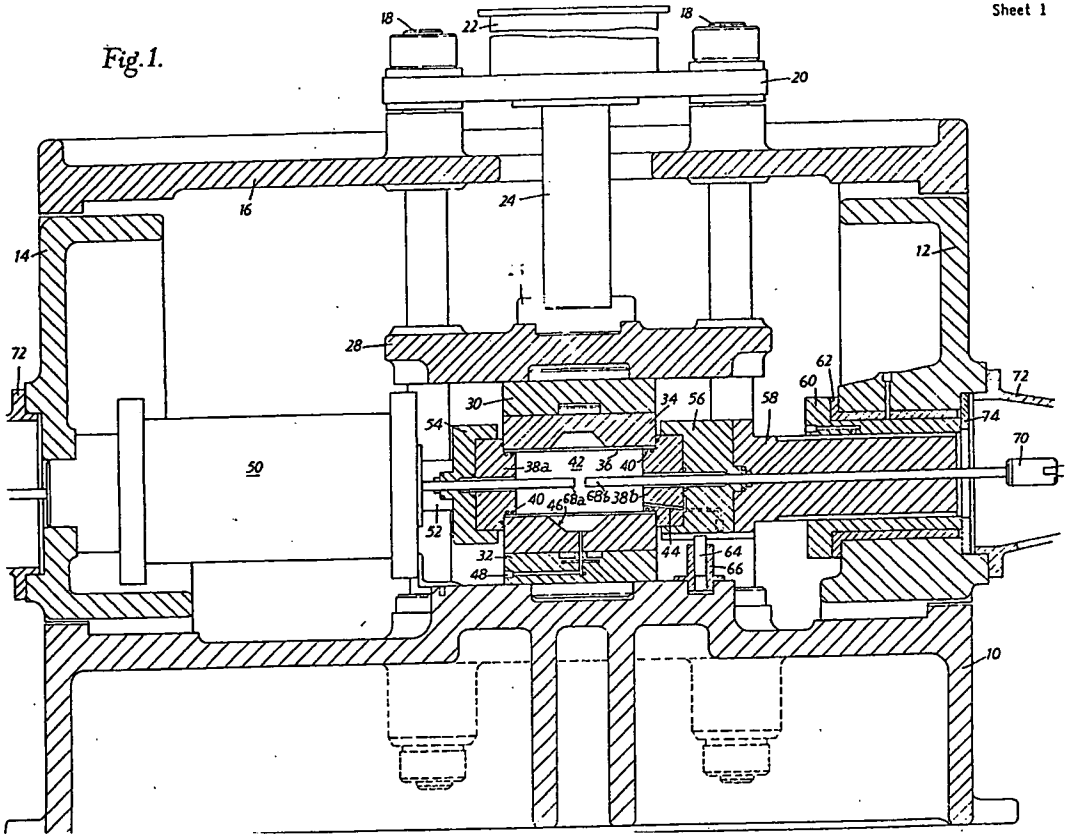
4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1



1165902 COMPLETE SPECIFICATION
4 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheet 1

Fig.1.



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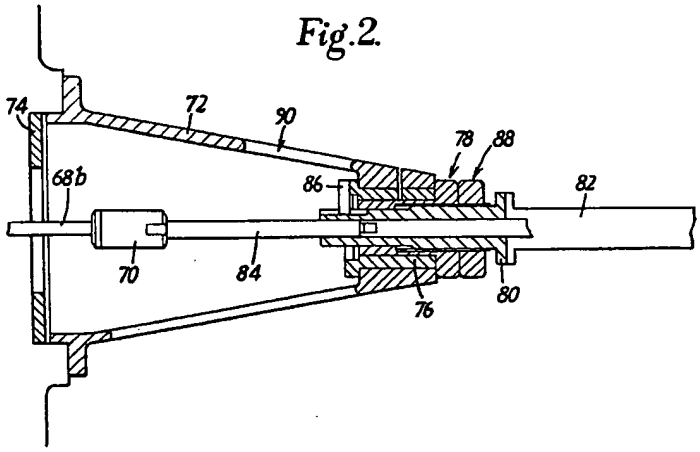
Sheet 2

Fig.2.



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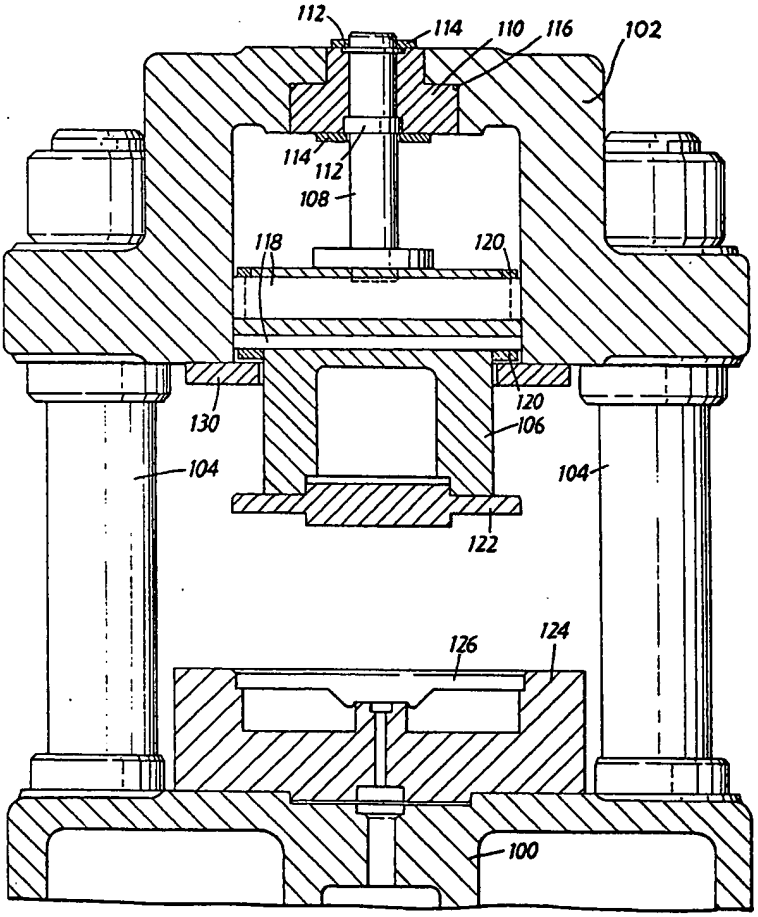
Sheet 3

Fig.3.



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Sheet 4

Fig.4.